Estimation of Horizontal Fluxes of Submicron Atmospheric Aerosol in the Middle Urals

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Abstract. The results of the estimation of submicron atmospheric aerosol horizontal fluxes by the method of Fluid Location of the Atmosphere (FLA) are presented. For this purpose, the three-dimensional problem of reconstructing the spatial structure of the aerosol distribution taking into account wet and dry deposition of aerosol particles on the underlying surface is solved numerically. The initial data were the results of photometric measurements during 2016 on the Middle Urals.

Keywords: Fluid Location of the Atmosphere, atmospheric aerosol, photometric measurements.

METHOD

The task of estimating the spatial structure of an aerosol concentration field by the FLA method is performed in three stages [1-3].

1. Statistical estimate of the average concentration field. At this stage, the average field of the measured parameter φ (such as pollutant concentration) is estimated on the basis of the Seibert method [4].

2. Euler stage. The average concentration field and the field of air motion velocities $\vec{v}$ are used to estimate the fields of sources/sinks; this is done using a conservation equation for the analyzed (instrument-measured) φ parameter in the Euler representation.

3. The Lagrange stage. The estimate of the source power field is used to calculate the distribution of the measured characteristic along each trajectory of motion of the Lagrange particle with the help of a conservation equation in the corresponding form.

As a result, it becomes possible to estimate the average flux $\overline{F_l}$ of a submicron atmospheric aerosol passing through a given vertical plane according to the formula:

$$\overline{F_l} = \overline{(v\varphi)_l} = \bar{v}_l\bar{\varphi}_l + \overline{v'_{l,k}\varphi'_{l,k}} \tag{1}$$

where, $\bar{v}_l$ – average for the considered period air velocity in the cell l; $\bar{\varphi}_l$ – average effective contaminant concentration for the cell l (calculated in stage 1); $v'_{l,k} = v_{l,k} - \bar{v}_l$ – particle k velocity deviation from $\bar{v}_l$; $v_{l,k}$– Lagrangian particle k velocity; k – number of the Lagrangian particle passing through the considered plane in the computational cell l; $\varphi'_{l,k} = \varphi_{l,k} - \bar{\varphi}_l$ – concentration deviation at the back trajectory point k from $\bar{\varphi}_l$.

RESULTS OF THE HORIZONTAL FLUXES ESTIMATION

The results of photometric measurements at the station of the global network AERONET [5], located on the territory of the Kourovo Astronomical Observatory near the city of Yekaterinburg, were used in the FLA simulation.

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The volume concentration of submicron aerosol (μm^3 / cm^3) was used as a characteristic of the aerosol content in the atmosphere. The volume concentration was calculated on the basis of the size distribution function of aerosol particles in an air column and an empirical model of the vertical profile of aerosol distribution for the region of Western Siberia [6].

The HYSPLIT software package [7-10] was used for calculation of back trajectories of air particles. The three-dimensional back trajectories lasting 96 hours (four days) each, starting every hour at the location of the AERONET network monitoring point at 6 levels from 500 to 5500 m were calculated.

Calculations of the three-dimensional field of submicron aerosol concentrations for the regions of the Middle Urals and Western Siberia [11] were carried out in the geographical location 30 ° –90 °E and 50 ° –70 °N. The height of the computational area was limited to 6 km. The dimensions of the Eulerian cells were set 1 ° x1 ° horizontally, and 1000 m vertically. To precise the calculated source power field, the algorithm of the FLA method includes models considering the intensity of physical sinks of aerosol particles. Sinks due to two key mechanisms for removing impurities from the atmosphere — wet [12] and dry deposition of aerosol particles on the underlying surface [13] —were taken into account.

Figure 1 shows the total average effective field of the submicron aerosol volume concentration (*$\mu m^3/\mu m^2$*). This field is the result of integration over the height of the aerosol concentration fields (*$\mu m^3/\mu m^3$*). The star signs mark the AERONET network monitoring points in the Middle Urals, as well as in Moscow and Tomsk. Cross-hatched regions are areas lying outside the zone of influence on the monitoring stations considered here. In the given case, the influence zone was defined as a region of space in which the number of trajectories per calculation cell was greater than unity. In addition, the boundaries of states are shown, as well as the coastline of continents and islands.

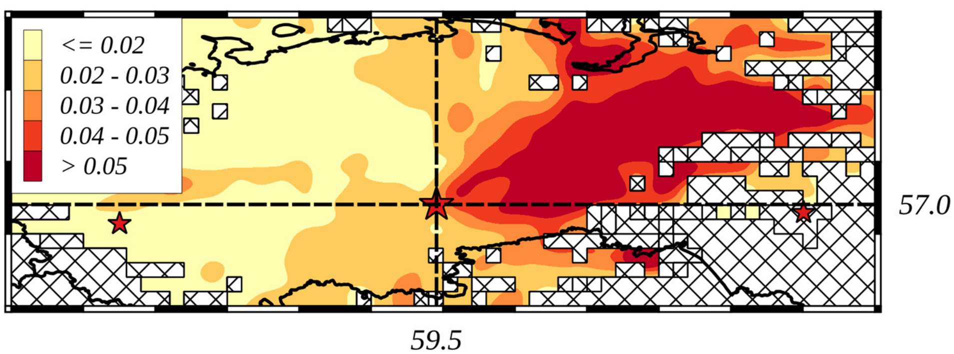

FIGURE 1. The average effective field of submicron aerosol volume concentration in 6 km column of the atmosphere (*$\mu m^3/\mu m^2$*).

Horizontal fluxes were estimated through two planes drawn along the meridians and latitudes through the monitoring point (dashed lines in Fig. 1). Figures 2a and 3a show the vertical distributions of the average effective fields of submicron aerosol volume concentration in the meridional and latitudinal planes, respectively.

The results of estimates of meridional and latitudinal fluxes are shown in Fig. 2b and 3b, respectively. The landscape is shaded in gray. A red triangle indicates the location of the measuring device.

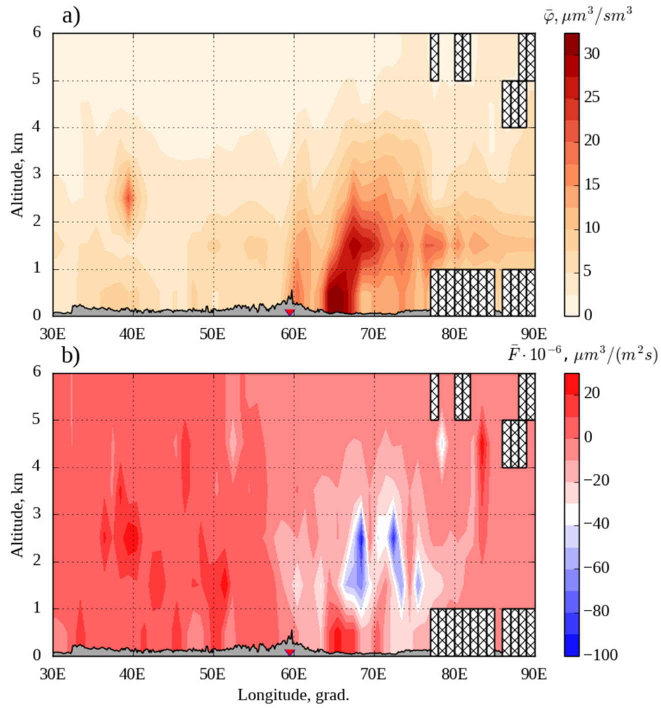

FIGURE 2. Assessment of the characteristics of a submicron aerosol in the Middle Urals in the meridional plane drawn through the monitoring station a) average effective concentrations calculated by the FLA method based on the results of photometric measurements in 2016; b) average fluxes calculated according to (1).

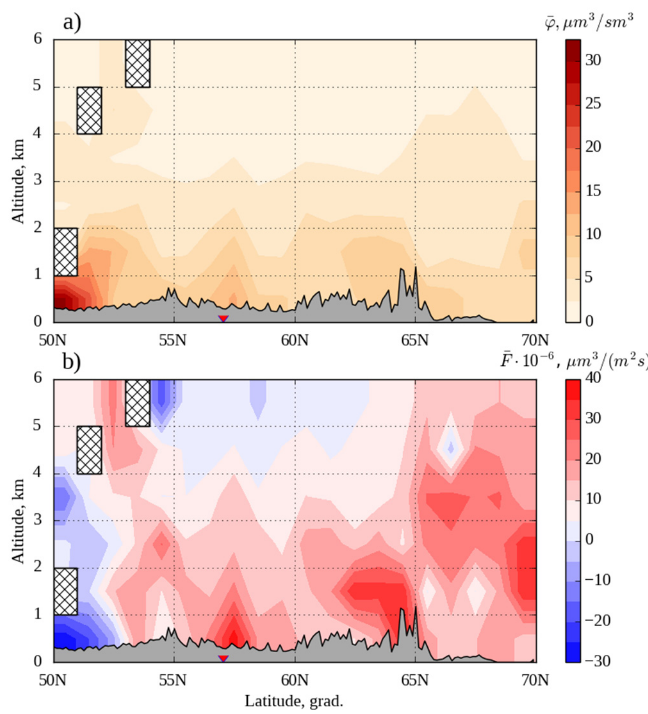

FIGURE 3. Assessment of the characteristics of a submicron aerosol in the Middle Urals in the latitudinal plane drawn through the monitoring station a) average effective concentrations calculated by the FLA method based on the results of photometric measurements in 2016; b) average flows calculated according to (1).

Figure 2b shows that the positive (directed from south to north) average flux of the submicron aerosol is realized in the region west of the monitoring point, while the eastern part is characterized by mostly negative (directed from north to south) aerosol fluxes. Large values of fluxes at altitudes of 1.5-2.5 km are probably the result of the transfer of smoke aerosols from the Siberian region in the summer of 2016.

As figure 3b demonstrates, aerosol transfer was mainly carried out from west to east. Reverse transfer from east to west was observed for the southern part of the calculated plane.

It can be seen from the figure 2b that in absolute terms maximum values were obtained for the meridional flux (about 100 $\mu m^3/(m^2\ s)$). However such large values are characteristic only for localized small areas, while in the greater part of the plane the average fluxes mainly shows lower values (about 20 $\mu m^3/(m^2\ s)$). Approximately the same lower values are typical for average latitudinal fluxes.

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